NEXTEP CONSULTING GROUP
808 Lyndon Lane
Suite 201
Louisville Ky 40222
P 502 . 339 . 9767
F 413 . 451 . 4859
E info@nextepcg.com

TECHNICAL MEMORANDUM 0707

June 11, 2007

Originator: Andrew H. Thatcher, CHP, Technical Director

Subject: ***Maximum Predicted Airborne Exposure Following a Worst Case Release from CFX Fuel Plates***

Revision: 0

ENDORSEMENT: This document contains the results of research and technical analysis which have been reviewed and approved for publication by:
6/15/07
Barton P. Anderson, Principal — Date

1 INTRODUCTION

1.1 PURPOSE

1.1.1 De-fueling of the Californium Neutron Flux Multiplier (CFX) at the Kodak facility is a complex, multi-step process that is fully detailed in the work plan[1]. The fuel assembly consists of 181 aluminum/uranium alloy MTR[2] type fuel plates. Because the fissile portion of these plates is completely covered by aluminum cladding to a thickness of 0.020", the plates are considered to be fully sealed sources and the likelihood of radioactive contamination from the plates is very low. Exposures associated with the steps involved in the work plan are estimated in the man-REM budget which has been published in NEXTEP Technical Memorandum (TM) 0706[3], and it makes no allowance for internal dose due to airborne radioactive contamination from the plates.

1 Eastman Kodak Co., CFX De-fueling Work Plan
2 Materials Testing Reactor
3 NEXTEP TM0706 *Kodak CFX De-Fueling Man-REM Budget*, A.H. Thatcher, CHP

1.1.2 The purpose of this paper is to consider and evaluate the worst case impact of unlikely events which have the potential to cause airborne contamination. Since the fuel plates are fully sealed sources such an event must come from cracked or damaged fuel plates. This could occur due to plate embrittlement from years of operation or, most likely, from accidental damage caused during handling. This technical memorandum will analyze the impact of a breach of 10 fuel plates at once and the predicted committed effective dose equivalent (CEDE) to a person in close proximity.

1.1.3 This paper will show that the predicted CEDE does not approach administrative limits and that any potential internal exposure does not merit further consideration.

1.2 BACKGROUND

1.2.1 The CFX has been in operation since 1975 and has been shutdown since June of 2006. The CFX was a sub-critical assembly of uranium 235 utilizing a californium 252 source[4]. The californium source has remained inserted into the CFX for most of the life of the CFX such that the total estimated operational hours are 252,000 at an average power of 5.8 watts. Further details of the CFX assembly and characteristics may be located in the EKC Scoping Study.[5]

2 SCOPE

2.1 This paper analyzes the predicted impact of a release following an accidental breach of a significant number of fuel plates (10 plates). Estimates are made based upon the contributions from the major isotopes contained in the fuel matrix.

3 METHODS

3.1 The release of airborne radioactivity is considered unlikely due to the nature of the material being handled and the double aluminum housing in which the material is encapsulated[6]. The scenario developed, therefore, is an accidental breach of fuel plate integrity and subsequent release of material which could become an airborne radiological hazard.

3.2 The accident scenario evaluated is an individual handling a stack of ten fuel plates (1.016 cm in thickness) and inadvertently tearing the stack of plates such that a 5 cm tear occurs in all ten plates. NEXTEP TM0603[7] provides the details on the size of the fuel plates while TM0519[8] provides the details on the total activity of the various fuel plates.

---

[4] The CFX was designed to never exceed a K_{eff} <0.99.

[5] NEXTEP TM0703 *Kodak CFX Scoping Study*, Robert Newman and Ning Zhang

[6] U.S.N.R.C. Safety Evaluation Report, Application Dated March 23, 1998 RE: License Renewal, Docket 70:1703.

[7] NEXTEP TM0603 Exposure Rate Estimates from Kodak MTR Fuel Plates. A.H. Thatcher, CHP.

[8] NEXTEP TM0519 Kodak CFX Core Residual Activity and Dose Modeling, A.H. Thatcher, CHP

3.2.1 The total exposed fuel plate area is calculated as follows:

Equation 1

$$\textit{Exposed Surface Area } (cm^2) = 5cm * 0.0508cm * 10 * 2 = 5.1\ cm^2$$

Where:

5cm	=	*length of tear in fuel plates*
0.0508cm	=	*thickness of individual fuel plates*
10	=	*number of fuel plates*
2	=	*two sides to a tear*

3.2.2 The volume of affected material (potentially releasable material) is estimated as 5.1 cm^2 times an assumed affected thickness of 0.1 cm, or 0.51 cm^3.

3.2.3 Other assumptions involved in the exposure calculation are as follows:

- A worker breathing rate of 1.2 m^3/hr.
- 0.002 of the material is available for release based upon a re-suspension factor for mechanical disturbances[9] of 4 E-02/m.

3.2.4 The fraction of material airborne is calculated as:

Equation 2

$$\textit{Fraction released} = \frac{\frac{0.04}{m}}{\frac{1}{0.1m}} = 0.004$$

Where:

4 e^{-02}	=	*re-suspension rate for mechanical disturbances*
0.1 m	=	*length of the material available for re-suspension*

- Total time spent breathing the re-suspended material is assumed to be 30 seconds[10].
- The contaminated material is contained within an average volume[11] of 1.6 m^3.
- The AMAD for the re-suspended particles is assumed to be 1 micron
- The recommended default solubility values for each radionuclide is used with the exception of U-235, where UF6 is a type F solubility.
- Total activity for each radionuclide of interest is obtained from Table 7 and 8 of TM 05-19.

---

9 NUREG 5512, Table 6.4. This value represents the upper bound value for mechanical disturbances. For further comparison, ANL-WHS-SE-000002, Commercial SNF accident release fractions, 2004, provides bounding estimates on the airborne release fraction for fuel and fission products. The bounding estimate from this document for a cask drop from 80" for Sr-90 is 6 E-07, as compared with 0.004. Other non gaseous fission products are estimated as high as .0002.

10 The worker causes the accident (perhaps by tripping), spends several seconds recovering from the accident, then, following the work plan, would simply set the material on the floor and walk away from the scene of the accident (thereby minimizing the exposure).

11 The initial volume of exposure is assumed to be ~30 cm (the distance from the fuel plates to the face). Assuming a diffusion rate of 2.5 cm/s, the resuspended volumetric cloud grows with time. The average volume is simply the time averaged volume of the contaminated material from time zero (radius of 30 cm) to 30 seconds (radius of 102.5 cm).

3.2.5 The activity released is estimated as follows:

Equation 3

$$Activity\ in\ volume\ of\ affected\ material = \frac{0.51}{2981} * Activity_{radionuclide}$$

Where:

0.51 cm^3	=	*affected volume of releasable material*
2,981 cm^3	=	*volume of all fuel plates (active fuel region)*
Activity$_{radionuclide}$	=	*the table 7 or 8 calculated activity for each radionuclide of interest for the CFX*

4 RESULTS

4.1 The calculated exposure, using Sr-90 as the example is calculated as follows:

Equation 4

$$\frac{Activity(\frac{Bq}{m^3})}{Volume(m^3)} * Fraction_{released} * Breathing_{rate}(\frac{m^3}{hr}) * ED(hr) * 10^5(\frac{mrem}{Sv}) * DCF(\frac{Sv}{Bq}) = 0.03 mrem$$

Where:

Activity (for Sr-90)	=	*1.3 E-05 Cu or 490,000 Bq*
Volume$_{average}$	=	*1.6 m^3* [12]
Fraction released	=	*0.004*
ED	=	*Exposure Duration = 30 seconds or 0.0083 hr*
DCF	=	*Dose Conversion Factor (ICRP 68) = 2.4 E-08 Sv/Bq*

4.2 The calculations for each major isotope are included as Attachment A.

4.3 The combined dose from all significant radioactive sources[13] in the cloud is approximately 0.1 mrem[14]. Since the administration limit for the radiological workers is 500 mrem/yr, this potential accident exposure is considered negligible and all further inhalation risks to workers from the fuel plates are removed from further consideration.

---

[12] Analysis was also performed for the immediate exposure following release. The assumed 0.14 m^3 volume shortly after release is associated with a much smaller exposure time of 3 seconds and resulted in a predicted dose of 0.116 mrem. The difference is not significant.

[13] All radionuclides with activity greater than 1 mCi were included. No DCFs are provided for inhalation of Kr-85 and Rh-106.

[14] Analysis was also performed focusing on the first few seconds of exposure to the smaller contaminated air volume. This analysis showed that the majority of the exposure occurs during the first few seconds of exposure as the cloud is quickly diluted.

5 CONCLUSIONS

5.1 The combined dose from all significant radioactive sources in the cloud is approximately 0.1 mrem (Section 4.3).

5.2 Since the administration limit for the radiological workers is 500 mrem/yr, this potential accident exposure is considered negligible and all further inhalation risks to workers from the fuel plates are removed from further consideration (Section 4.3).

ATTACHMENT A

CEDE from Significant Radionuclides Following Release

Radionuclide	Activity (Ci) for CFX	Activity in affected volume (Bq)	Average volume of cloud (m^3)	Release Fraction	Breathing Rate (m^3/hr)	Exposure Duration (hr)	Conversion of Sv to mrem	DCF (Sv/Bq)	Dose (mrem)
Sr-90	0.0781	494874.949	1.6	0.004	1.2	0.00833	1.00E+05	2.40E-08	2.97E-02
Y-90	0.0781	494874.949	1.6	0.004	1.2	0.00833	1.00E+05	1.40E-09	1.73E-03
Y-91	0.00213	13496.5895	1.6	0.004	1.2	0.00833	1.00E+05	6.70E-09	2.26E-04
Zr-95	0.00342	21670.5803	1.6	0.004	1.2	0.00833	1.00E+05	4.50E-09	2.44E-04
Nb-95	0.00737	46699.467	1.6	0.004	1.2	0.00833	1.00E+05	1.40E-09	1.63E-04
Ru-106	0.00555	35167.1699	1.6	0.004	1.2	0.00833	1.00E+05	1.80E-08	1.58E-03
Cs-137 (and Ba-137m)	0.0803	508815.088	1.6	0.004	1.2	0.00833	1.00E+05	4.80E-09	6.10E-03
Ce-144	0.0619	392224.831	1.6	0.004	1.2	0.00833	1.00E+05	3.40E-08	3.33E-02
Pr-144	0.0619	392224.831	1.6	0.004	1.2	0.00833	1.00E+05	1.80E-11	1.76E-05
Pm-147	0.0503	318722.278	1.6	0.004	1.2	0.00833	1.00E+05	4.70E-09	3.74E-03
Sm-151	0.00227	14383.6893	1.6	0.004	1.2	0.00833	1.00E+05	3.70E-09	1.33E-04
U-235	0.00343	21733.9446	1.6	0.004	1.2	0.00833	1.00E+05	5.10E-07	2.77E-02
								CEDE	**1.05E-01**